APPENDIX L

RESTORATION DESIGN SCENARIOS

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RESTORATION DESIGN SCENARIOS

L.1 INTRODUCTION AND BACKGROUND

Riverbank and riverbed restoration are necessary and important elements in the remediation of the 1½-mile EE/CA Reach. This appendix presents a detailed description of conceptual restoration scenarios that can potentially be applied within the EE/CA Reach. An analysis of restoration options has been conducted, the results of which have been presented in Sections 4 and 5 of the EE/CA Report. The design scenarios presented below have been developed based on a preliminary analysis of anticipated river flow and erosional characteristics, as well as general assumptions regarding restoration of habitat. These design scenarios are consistent with both the primary remediation goals and the habitat restoration objectives for the project. As noted below, final design of restoration schemes for both riverbanks and the riverbed will require additional data gathering and analysis, as well as further development of specific habitat restoration goals, particularly for the riverbed.

The paragraphs below provide an introduction to and descriptions of the restoration scenarios, which for the riverbanks are depicted schematically. The schematics show potential stabilization concepts; other methods within each technology are also equally feasible. Further quantification of specific on-site conditions (e.g., location of sorptive cap, stream cross sections after soil is removed) and detailed analyses (i.e., geotechnical, hydraulic, and geomorphic) are needed to fully assess the various technologies before a final restoration design can be selected.

L.2 RIVERBANK RESTORATION

Figures L-1 through L-3 illustrate three riverbank stabilization techniques. Each figure shows the general design details in both the stream cross-sectional view and the longitudinal perspective through an isometric schematic. The schematics correlate to the three technology groups discussed in the riverbank restoration descriptions in Sections 4 and 5 of the EE/CA Report: revegetation, bioengineering structures, and hard structures. Each schematic also depicts how the stabilization project will look immediately following construction (as-built), and 5 years and 20 years after construction.

Schematics represent conceptual designs. Their objective is to show the features of the design and how the riverbank may look over time. All schematics are not drawn to scale. Since some riparian vegetation species may grow relatively fast (e.g., eastern cottonwood can average 3 to 5 ft/yr depending on site conditions [USDA, 1965]), the 5-year and 20-year perspectives are reduced (approximately 30%) in size to illustrate differences in riparian vegetation growth.

Schematics use current on-site conditions (e.g., stream cross sections, flood levels, bank heights) and projected conditions after remedial measures are complete (e.g., bank slope, sorptive cap location, amount of fill). Where a sorptive cap is installed in the lower bank, the cap is assumed to extend up the bank approximately 3 to 6 ft from the edge of the streambed. In addition, armor stone is placed along the lower slopes in the revegetation and bioengineering scenarios for toe of slope stabilization and to meet the requirements of the conceptual riverbed armor design (Appendix M), which indicates the need for armor up the banks to approximately the 2-year flood level (up to about 6 ft above the mean flow level). Where a retaining wall is required at the toe of the slope, the restoration design would follow the concepts presented in Appendix N (Bank Stability Evaluation). Since bank slope affects the restoration technology selected, each schematic has a bank slope that fits its respective design. Bank slopes for revegetation, bioengineering, and hard structures are, respectively, <3H:1V, >3H:1V to <2.25H:1V, and >2.25H:1V.

Another criterion that affects the restoration design is the channel cross section after contaminated soil is removed. Channel cross-section affects hydraulic geometry and subsequent flood stage heights and bank shear stresses. Depending on the design discharge selected, these hydraulic characteristics will then be used to assess the stability of design features and their associated placement (e.g., riprap size and slope length). Appendices M (Cap Design and Construction Evaluation) and N (Bank Stability Evaluation) include evaluation of those elements and resultant conceptual design information for bank stabilization.

The restoration schematics assume that contaminated soils along the bank are removed (up to 3 ft, if needed) and replaced with a similar, suitable growth medium. The schematics also assume that a similar channel cross section would result after cleanup because the Housatonic River's floodplain in the EE/CA Reach is limited due to the civil infrastructure. For example, in Subreach 4-1 current bank slopes are relatively steep (up to 1H:1V). After soil removal, a steep bank slope would still be needed as roads/power lines will still be present. Each schematic uses an existing channel cross section that fits the bank slope requirements for the respective restoration technology.

A secondary criterion used to select representative channel cross sections was channel slope. Average channel slopes range from flat to 0.5% within the EE/CA Reach. Channel slope affects discharge and associated hydraulic conditions (e.g., bank shear stress). A different channel slope is selected for each schematic. They include 0.1%, 0.2%, and 0.5%. Also, all channel cross sections are taken from straight, riffle reaches. Riverbank restoration analyses for other geomorphic forms (e.g., meander bends, pools) would be different and should be addressed in final restoration designs (USDA et al., 1998; Veri-Tech, 1998).

Using channel cross sections and estimated flood frequencies (USACE, 1998), the 10-year floodplain map (Blasland, Bouck and Lee, 1992), field observations (i.e., bankfull discharge stage heights), and discharge measurements (Roy F. Weston, Inc., 1999) flood stages were back-calculated for each schematic. The 10-year floodplain map indicates that this event is generally associated with the top of the channel banks throughout the EE/CA Reach.

Manning's equation was used for hydraulic analyses. Roughness values were adjusted until the 10-year flood stage was approximately equal to the elevation of the top of the channel banks. Average roughness values ranged from 0.04 to 0.1 depending on the subreach. Channel bed

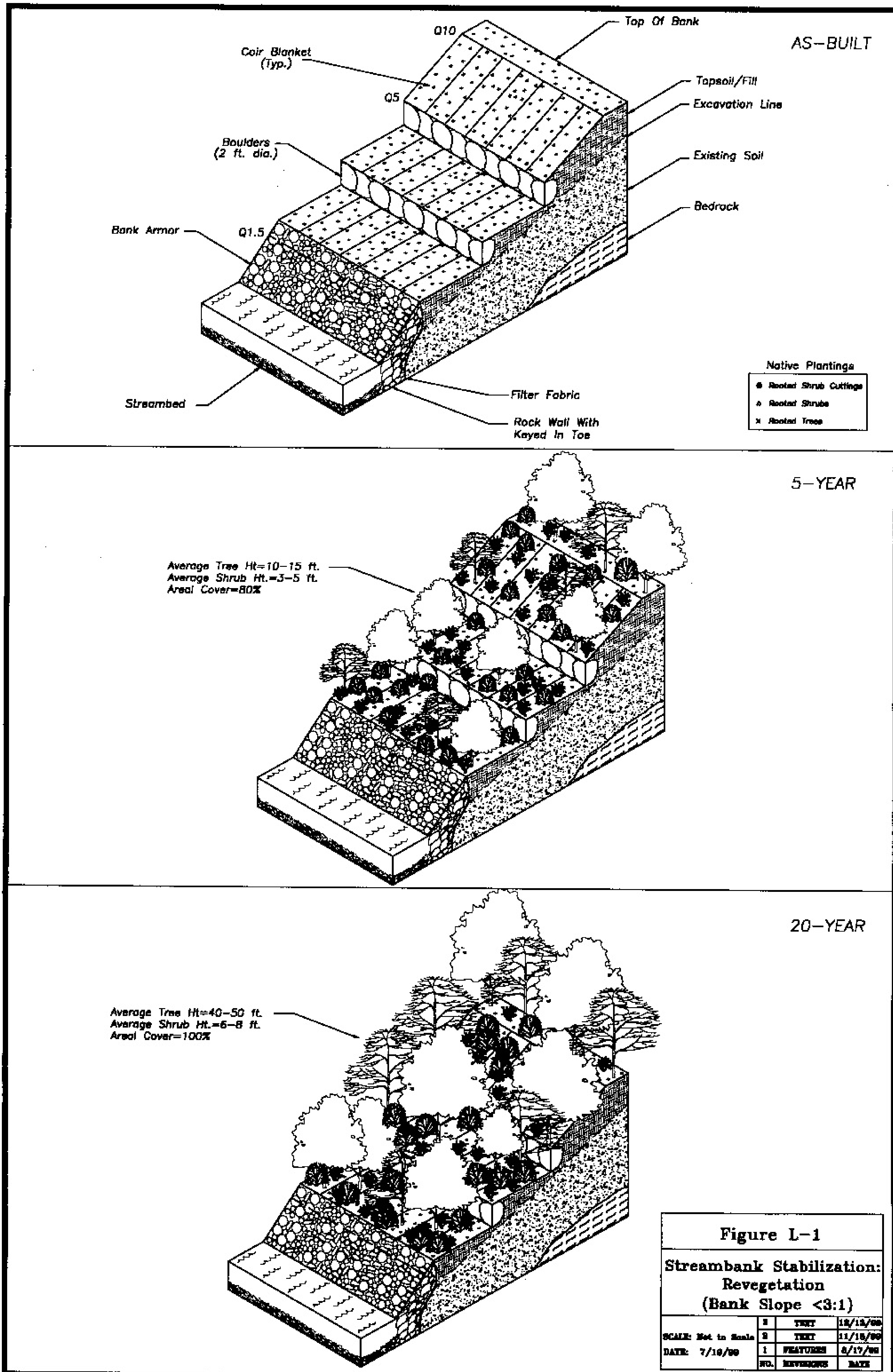

Figure L-1

Streambank Stabilization: Revegetation (Bank Slope <3:1)

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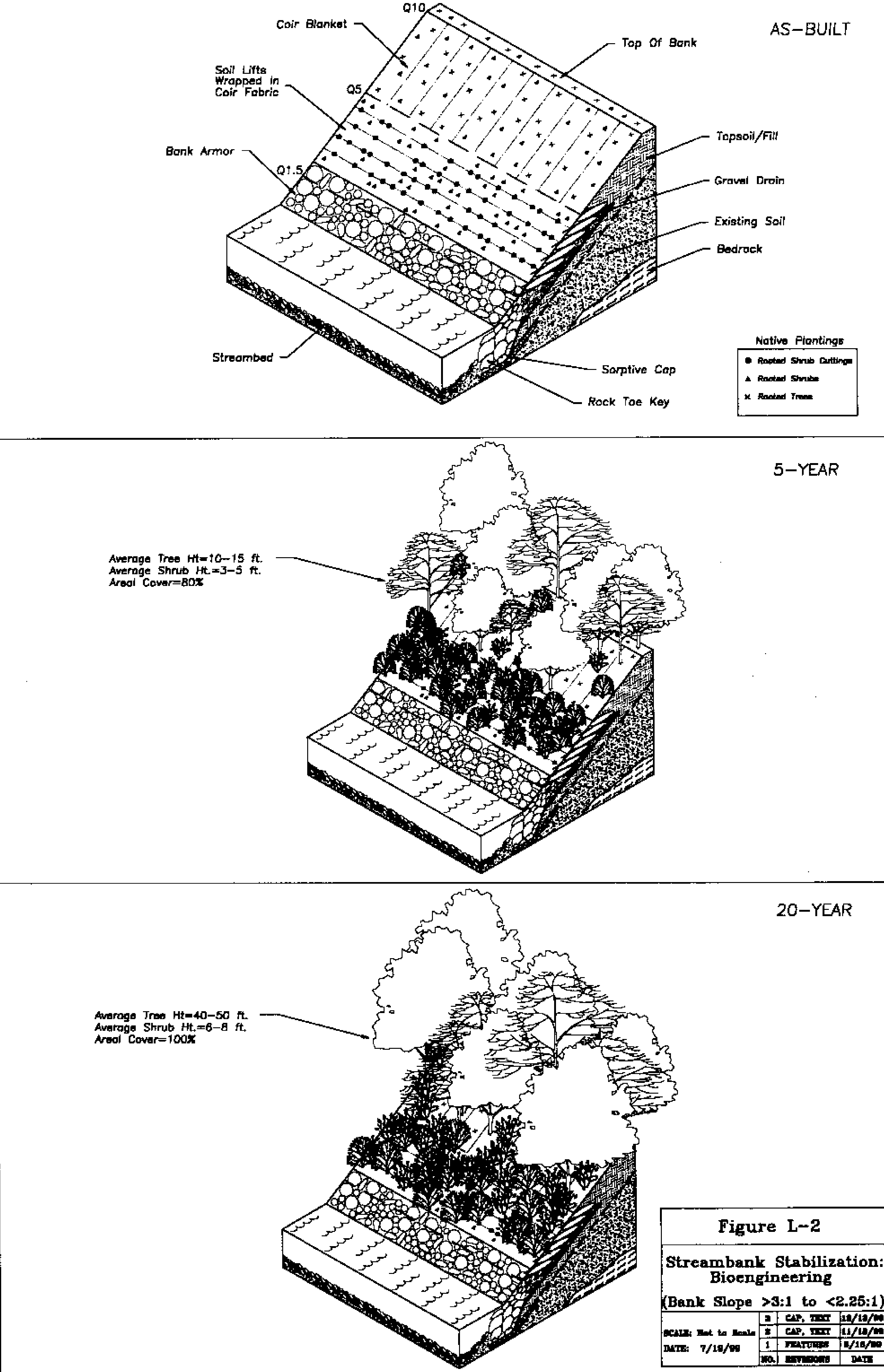

Figure L-2

Streambank Stabilization: Bioengineering

(Bank Slope >3:1 to <2.25:1)

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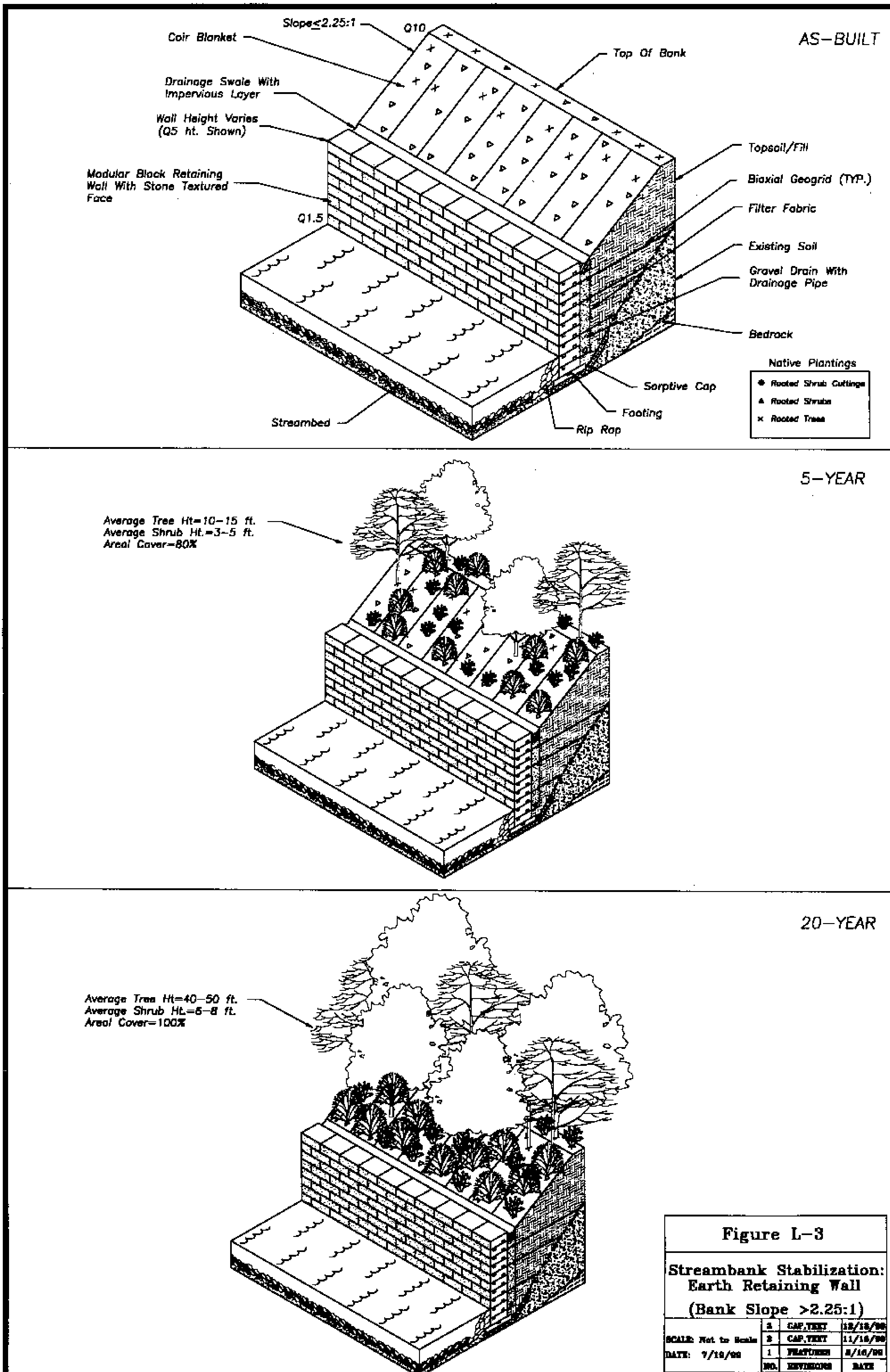

Figure L-3

Streambank Stabilization: Earth Retaining Wall

(Bank Slope >2.25:1)

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2	CAP.TEXT	11/16/99
1	FEATURES	8/16/99

slope was assumed equal to the water surface slope (Chow, 1959; Leopold et al., 1964) and remained constant through various discharges. Hydraulic analyses resulted in flood stages for the 1.5- (bankfull), 5-, and 10-year floods; these are shown on each schematic. Discharge values for these floods are approximately 900, 3200, and 4300 cfs, respectively (Norvitch et al., 1968; USACE, 1998; and Blasland, Bouck, and Lee, 1999).

Average velocities and average shear stresses for the respective flood stages are listed below in the schematic descriptions. Flood stage as well as bank height measurements begin from the deepest part of the channel. The hydraulic characteristics calculated are based on the existing channel cross sections, some of which were modified to include design features (e.g., constructed terraces). Roughness values were based on existing conditions (i.e., with vegetated banks) and assumed to be constant through the discharge ranges (roughness values typically decrease with increasing stage [Richards, 1982]).

After soil remediation work is complete, roughness values are likely to change (e.g., less riparian vegetation, more in-channel roughness [e.g., boulders]). Changes in roughness values as well as more detailed information on roughness values at higher stages will likely change the estimated average velocities and shear stresses presented in the schematics. Such effects need to be considered in future analyses.

The flood events chosen were based on their geomorphic significance (i.e., channel forms and processes) and the extent of flood water inundation (Leopold et al., 1964; Rosgen, 1996). Such events are essential in the design process of plantings as well as specific stabilization features (e.g., armor heights).

The schematics illustrated were selected based on the EE/CA habitat restoration objectives (i.e., to protect banks from erosion and to increase aquatic/riparian habitat diversity) and the geomorphic and hydraulic characteristics of the Housatonic River (e.g., hydrology, soil characteristics, river form, etc.). Information regarding environmental factors (e.g., ice scour), aesthetics, design implementation, performance, and costs were also considered.

Listed below is a general description of each riverbank restoration schematic. Also, described separately, is a description of the riparian revegetation methodology, which is the same for all of the schematics.

L.2.1 Riverbank Restoration Schematics

L.2.1.1 Revegetation

Shown in Figure L-1 is the revegetation schematic. There is no sorptive cap present in this design. The composite bank slope is approximately 3H:1V with a bank height of 16 ft. Subreaches that may have applicable bank slopes include portions of 3-8, 3-9, and 4-3 to 4-5. A representative channel cross section was used to determine approximate flood stage levels and associated hydraulic characteristics (station 41+50, subreach 4-3). Average channel slope is 0.2% with a Manning's roughness value of 0.08.

Revegetation alone is not likely to meet the habitat restoration objectives (i.e., protect banks from erosion). A toe foundation is needed (see also Appendix N) as the potential for erosion is high on slopes that do not have established riparian vegetation. Riprap is used to stabilize bank slopes from bank undercutting and subsequent slump failures (see also Appendix M).

This restoration concept mimics geomorphic processes; terraces are created at stage levels that correspond approximately to the 2- and 5-year flood events. These terraces create planting sites for riparian vegetation and help reduce streambed shear stresses and subsequent erosion by spreading out flood discharges. This restoration concept uses an armor layer (riprap) to protect the lower bank from low flow to the approximate 2-year flood level. Rock walls constructed to create terraces are depicted as 2 ft high.

It is again noted that Appendix M states that armoring of the riverbank will generally be conducted up to approximately the 2-year flood level (approximately 6 ft above average river level). Terrace widths range from 10 to 15 ft with slopes ranging from flat to 10H:1V. Terrace elevation could be adjusted to fit into other existing terraces upstream or downstream of the restoration site to increase floodplain area. It is also noted that the use of terraces in this scenario will have to be coordinated with the excavation process, and where extensive additional excavation is required, will likely have to be limited due to space constraints.

The rock wall terrace is made of angular rock. Rock size depends on scour analysis but typically D_{50} ranges from 12 to 24 inches (Miller and Hoitsma, 1998; Johnson and Stypula, 1993). As the design process evolves, these walls could also be combined with bioengineering technologies or with another type of hard structure (e.g., pre-cast concrete blocks). Coir fabric (biodegradable coconut fiber erosion blanket) is stapled onto the terraces and plantings are placed through the fabric. The coir fabric provides protection from erosion and helps maintain soil moisture for riparian plantings. Coir fabric has shear stress resistance ranging from 2 to 3.0 lb/ft^2 with life spans of 5 to 7 years (Reagan, 1999).

Table L-1 lists the flood stages (measured from the bottom of the channel), shear stresses, and average velocities for the 1.5-, 5-, and 10-year flood events. Low-flow stage is approximately 3 ft. These hydraulic characteristics, along with additional geotechnical and geomorphic analyses, need to be assessed to further develop conceptual features into design plans (e.g., armor size, thickness, and grade).

Table L-1

Average Velocity and Shear Stress for Various Flood Stages in the Revegetation Schematic

Flood Event	Stage Height (ft)	Avg. Velocity (ft/s)	Avg. Shear Stress (lb/ft^2)
1.5-Year	7	2.4	0.6
5-Year	13	3.3	1.0
10-Year	16	3.7	1.2

The revegetation restoration technology is relatively inexpensive to install, uses on-site materials, and establishes a riparian vegetation community. Success of plantings depends on the plants, installation, and maintenance as well as environmental factors (ice scour, weather, etc.).

L.2.1.2 Bioengineering

The bioengineering schematic is presented in Figure L-2. A sorptive cap for the lower bank is present in this design and is shown with a 6-inch sorptive layer and 6-inch filter layer. Bank slope is approximately 2.25H:1V to as shallow as 3H:1V. Subreaches that may have applicable bank slopes include portions of 3-8, 3-9, 3-10, 4-1, and 4-3 to 4-6. A representative channel cross section was used to determine approximate flood stage levels and associated hydraulic variables (station 4+50, subreach 3-8). Average channel slope is 0.1% with a Manning's roughness value of 0.04.

This restoration concept utilizes an armor layer (riprap) to protect the sorptive cap from low flow to slightly above the 1.5-year flood level. As noted in Appendix M, the armor may extend up the bank to an elevation up to 6 ft above the water line, or to approximately the 2-year flood level. This height can be adjusted to fit different locations of the sorptive cap. The armor layer is made of uniform angular rock and a keyed-in toe, and is lined with a filter blanket (graded, finer material and/or filter fabric). Uniform riprap generally provides more stability than a well-graded riprap (Wittler and Abt, 1990; Maynord, 1988). For these size rivers the toe is typically installed 3 ft below the thalweg and uses a D_{50} of 12 to 24 inches (Miller and Hoitsma, 1998; Johnson and Stypula, 1993). Toe slope design is critical to prevent scour and subsequent slope failure of this design (Verdi, 1998; Franklin County et al., 1998). A conceptual geotechnical analysis is presented in Appendix N.

A riverbed armor layer design is described in detail in Appendix M, and is similar to that proposed by GE for the Upper ½ Mile Source Reach that is immediately upstream of the EE/CA Reach. The armor layer was calculated to be stable up to an approximately 30-year event using a 6-inch layer of sand and gravel and an 18-inch layer of D_{100} 12-inch stone. Riverbed armor stone will only be placed in those areas of the river where hydraulic analysis indicates the need for armor stone to prevent excessive erosion, such as the cobble reach.

The fabric-encapsulated soil method (Miller and Hoitsma, 1998) is used to stabilize the bank slope from approximately the 2-year to 5-year flood stage (stage heights from approximately 6 to 10 ft, a slope length of approximately 9 ft). The method uses soil lifts (two layers of coir blankets wrapped in soil, anchored, and stacked on top of each other). Soil and rooted shrub cuttings are placed between the lifts. Annual rye seed is broadcast on any bare soil areas to provide short-term erosion control. The lifts are supported by the riprap toe foundation. A gravel filter is located under the soil lifts to add drainage. Applications of this method have shown it can resist shear stresses up to 2.1 lb/ft^2 (Miller and Hoitsma, 1998).

Container stock shrub species are planted through the coir fabric on the top of each lift. Depth to existing contaminated soil is assumed to be less than 5 ft. Only shrubs and grasses are planted in this area as tree species may eventually grow into contaminated soil and subsequently expose this soil if the tree falls over.

Coir fabric and container stock of trees and shrubs are transplanted into the bank slope from the 5- to 10-year flood stage (stage heights from 10 to 12 ft, a slope length of 5 ft). Where trees with deep root zones will be planted, depth to existing soil should be greater than 5 ft. Annual rye seed is broadcast on all bare soil. Coir fabric is rolled out perpendicular to the river and anchored to the soil. Riparian plantings are then transplanted through cut-out portions of the coir fabric. Subsequent root growth will add stability to this slope (Callahan, 1999).

Table L-2 lists the stage heights (measure from the bottom of the channel), shear stresses, and average velocities for the 1.5-, 5-, and 10-year flood events. The low-flow stage is 3 ft. These hydraulic characteristics along with additional geotechnical and geomorphic analyses need to be assessed to further develop conceptual features into design plans (e.g., armor size, thickness, and grade).

Table L-2

Average Velocity and Shear Stress for Various Flood Stages in the Bioengineering Schematic

Flood Event	Stage Height (ft)	Avg. Velocity (ft/s)	Avg. Shear Stress (lb/ft^2)
1.5-Year	5.5	3.0	0.3
5-Year	10	4.4	0.4
10-Year	12	4.9	0.5

Other bioengineering designs were reviewed (live fascine, brush mattress, crib walls, etc.) and they may be equally suited to stabilize bank slopes (Schiechtl and Stern, 1997). The restoration schematic presented meets the overall restoration objectives: protects the sorptive cap and existing contaminated soil, stabilizes the bank with vegetation, and in the long-term, establishes a riparian vegetation that adds diversity and complexity to the riparian ecosystem. The bioengineering restoration technology is relatively inexpensive to install, but can require more extensive planning, preparation, and construction oversight than the other restoration schematics. Success of plantings depends on the plants, installation, and maintenance as well as environmental factors (ice scour, weather, etc.).

L.2.1.3 Hard Structures

The hard structure schematic is shown in Figure L-3. This schematic shows a retaining wall with reinforced soil slopes. A sorptive cap for the lower bank is present in this design and is shown with a 6-inch sorptive layer and a 6-inch filter layer. The composite bank slope is approximately 1H:1V with a bank height of 20 ft. A representative channel cross section was used for this bank slope to determine approximate flood-stage levels and associated hydraulic variables (station 23+00, subreach 4-1). Average channel slope is 0.5%.

As stated above, the riverbed armor layer design is described in detail in Appendix M, and is similar to that proposed by GE for the Upper ½-Mile Source Reach that is immediately upstream of the EE/CA Reach. The armor layer was calculated to be stable up to an approximately 30-year event using a 6-inch layer of sand and gravel and an 18-inch layer of D_{100} 12-inch stone. Riverbed armor stone will only be placed in those areas of the river where hydraulic analysis indicates the need for armor stone to prevent excessive erosion, such as the cobble reach.

This illustration shows a concrete, modular block wall. The blocks are prefabricated, interlockable, and have a stone-textured appearance. The elevation of the top of the wall will be set in order to meet the design criterion of 2.25H:1V for the slope above the wall. In this illustration, the height of the wall extends from low flow up to the 5-year event (approximately 13 ft). Slope of the wall face is nearly vertical (1H:12V). The wall is set on a concrete gravel foundation and armored with riprap. Like other restoration methods, stabilization of the toe is essential for project success. The foundation is generally installed about 3 ft below the thalweg (Martin, 1999; Smith, 1999). Refer to Appendix N for the conceptual design of a retaining wall developed for the EE/CA.

A gravel drain (typically 0.75-inch gravel) is placed immediately behind the wall with a drain outlet at the base to aid groundwater drainage and to prevent hydrostatic loads on the wall. Filter fabric is placed between the fill and the drain to prevent fines from clogging the drain. A small swale is created on top of the wall with an impervious layer installed below to also aid drainage. Where the sorptive cap ends, filter fabric is used between the existing soil and the fill. Biaxial geogrids are used in the fill behind the wall to add additional stability to the wall (Martin, 1999; Sabatini et al., 1997).

From the top of wall to the top of bank the fill slope is soil (stage heights from 16 to 20 ft, a slope length of 9 ft). Coir fabric and container stock of tree and shrubs are transplanted into the bank slope. Annual rye seed is broadcast on all bare soil. Coir fabric is rolled out perpendicular to the river and anchored to the soil. Riparian plantings are then transplanted through cut-out portions of the coir fabric. Depth to existing soil is greater than 5 ft. Only shrubs are planted within 6 ft of the top of the wall as tree roots may reduce the structural integrity of the wall (e.g., drainage or the trees may be blown down).

Table L-3 lists the stage heights (measure from the bottom of the channel), shear stresses, and average velocities for the 1.5-, 5-, and 10-year flood events. The low-flow stage is 3 ft. These hydraulic characteristics, along with additional geotechnical and geomorphic analyses, need to be assessed to further develop conceptual features into design plans (e.g., foundation size, spacing and length of geogrids).

Other earth-retaining wall structures may be equally suited to stabilize bank slopes (see Appendix N). The restoration schematic presented meets the overall restoration objectives: it protects the sorptive cap (where used) and remaining contaminated soil and stabilizes the bank. This schematic also meets secondary restoration objectives (i.e., riparian vegetation) where some of the other types of retaining walls do not.

Table L-3

Average Velocity and Shear Stress for Various Flood Stages for the Hard Structure Schematic

Flood Event	Stage Height (ft)	Avg. Velocity (ft/s)	Avg. Shear Stress (lb/ft^2)
1.5-Year	8	2.9	1.6
5-Year	16	4.1	2.8
10-Year	20	4.6	3.2

The concrete block wall with a reinforced soil slope is durable, establishes riparian vegetation, resists environmental factors (e.g., ice scour), installs quickly, adapts to various designs (e.g., concave bend), and is aesthetic. These walls may be more costly than the other restoration schematics and may require that additional soil be removed or filled depending on the final designs. Success of plantings depends on the plants, installation, and maintenance as well as environmental factors (ice scour, weather, etc.).

L.2.1.4 Riparian Plantings

This section discusses the riparian planting objectives, methodologies, and design considerations for the schematics illustrated. A more detailed riparian planting assessment is needed to address availability of plantings, number and age classes of species, propagation contracts, planting guidelines and schedules, weed control, on-site maintenance, animal and vandalism damage, watering, mulching, and fertilization.

The overall objective for habitat restoration and enhancement is to restore and enhance habitat at each stabilization project to the maximum extent possible, given site and remedial requirements. This entails establishment of natural plant communities in high-floodplain forests that currently exist adjacent to the Housatonic River.

Another primary objective of riparian habitat restoration will be to restore the structural diversity of each community in as short a time as possible. Diversity includes the physical ground structure (e.g., microtopography) and the biological structure (e.g., uneven aged trees, and diversity of species). The riparian revegetation used in these schematics follows these general guidelines.

Fill material will be selected from a structural standpoint and also from a riparian restoration perspective as the fill material affects the survival and growth of riparian plantings. There will, however, be places within all schematics where different fill material is needed to ensure geotechnical stability (e.g., retaining wall drainage features). The amount of plantable area is highest with the revegetation technology and lowest with the retaining wall.

Native species were selected based on their inundation tolerance, success of transplanting, rooting habit and depth, size, and growth rates (USDA, 1965; Franklin County et al., 1998; Kearsley, 1998; Woodlot Alternatives et al., 1999; Woodlot Alternatives, 1999). All plantings are rooted container stock unless otherwise noted. These types of transplants have a lower mortality rate than cuttings.

The schematics show general locations of plantings and their associated projected growth 5 years and 20 years after planting. Tree growth rates were based on eastern cottonwood since it is a primary canopy species. An average growth rate of 3 ft per year is used (USDA, 1965). This growth rate assumes moderate growing conditions (e.g., precipitation, soil, etc.). Growth rate of shrubs is based on field observations of silky and red osier dogwood (avg. 1 ft/yr up to maximum height of 8 ft). Both dogwood species reach a maximum height after approximately 10 years. After transplanting, growth rates are low the first 2 years because of shock; more vigorous growth then begins. Growth rates level off as the species matures (e.g., eastern cottonwood 25 to 30 years [USDA, 1965]). Growth rates are indices of potential; actual growth rates will depend on soil conditions, weather, health of plants, competition, maintenance, etc.

Broadcasting annual rye seed *(Lolium perenne*) on all bare soil where bank slopes are 2H:1V or less and will help establish an initial root mass, prevent weed invasion, and reduce surface erosion. The approximate broadcast rate is 15 lb/acre (Woodlot Alternatives et al., 1999). Coir fabric is rolled out perpendicular to the river and anchored to the soil. Riparian plantings are then transplanted through cut-out portions of the coir fabric.

To simplify the schematics only a limited number of plants are illustrated. The schematics show the general plant spacing patterns. Planted trees are 4 to 6 ft tall with an average spacing between trees of 5 ft. Trees are planted parallel to the river in unevenly spaced rows. Shrubs are planted in oblong patches (30 by 50 ft) spaced approximately 40 ft apart. Planted shrub heights are 2 to 3 ft tall with an average spacing between shrubs of 5 ft within the patches (Woodlot Alternatives et al., 1999; Blasland, Bouck & Lee, 1999). Natural revegetation and pruning will help to add some diversity of age classes and landscape patterns over time. The herbaceous strata in the form of seeds and plugs can be added to further enhance riparian vegetation.

Native species selected within the flood stages of the 1.5- to 5-year, 5- to 10-year, and greater than 10-year floods are shown in the Table L-4. For a given planting area approximately 75% of the species planted are primary species and 25% are associate species.

Cuttings that will be used between soil lifts are 4- to 5-ft rooted cuttings and are spaced 4 ft apart. Special handling and transplanting times will need further consideration as planting times are limited by the soil lift construction schedule; cuttings will need to be placed between the lifts during construction time, which may not correlate with the ideal planting times. Broadcasting of annual rye seed occurs both under and over the coir fabric. Rooted container shrubs are planted into the soil lifts through cut-out portions of the coir fabric at an average spacing of 5 to 6 ft on center.

Table L-4

Native Trees and Shrubs to be Planted Within Various Flood Stage Ranges

Flood Stages	Trees	Shrubs
1.5-5 year	Primary: Black willow (*Salix nigra*) Silver maple (*Acer saccharinum*). Associates: eastern cottonwood (*Populus deltoides*) and box elder (*Acer negundo*)	Primary: Silky dogwood (*Cornus amomum*) Associates: Red osier dogwood (*Cornus sericea*)
5-10 year	Primary: eastern cottonwood and box elder. Associates: silver maple and American elm (*Ulmus americana*).	Primary: Silky and red osier dogwood Associates: Northern arrowwood (*Vibrurnum dentatum*) and Winterberry holly (*Ilex verticillata*)
>10 year	Primary: eastern cottonwood and box elder. Associates: silver maple and American elm	Primary: Red osier dogwood Associates: Silky dogwood, Northern arrowwood, Smooth Shadbush (*Amelanchhier laeuis*), black raspberry (*Rubus occidentalis*), and Winterberry holly

Where a sorptive cap is used, a maximum fill depth of 5 ft will be needed for trees to be planted. Species like eastern cottonwood (*Populus deltoides*) can have rooting depths of 5 ft and may degrade the integrity of the sorptive cap. For example, in the bioengineering schematic, the depth from the soil lifts to contaminated soil may be less than 5 ft; only shrub species are planted in this area. It is likely that in many bank areas, depth to underlying bank soils will be no more than 3 ft, and therefore planting of deep rooting trees will be limited due to uprooting concerns.

Indigenous woody vines are also planted 3 years after initial plantings to ensure that canopy species are not overtaken. River grape (*Vitis riparia*) and virgins bower (*Cleamatix virginiana*) are planted on 4-ft centers in small oblong patches (15 by 30 ft). Patches are spaced approximately 150 ft apart (Woodlot Alternatives et al., 1999).

L.3 RIVERBED RESTORATION SCENARIOS

Riverbed restoration will be conducted in accordance with both the Removal Action Objectives and the Habitat Restoration Objectives. Depending on the river configuration, original substrate, and flow regime, different types of riverbed restoration and habitat enhancement techniques will be used. This section provides a conceptual-level description in tabular and text form of the riverbed restoration techniques and design elements that will likely be appropriate for the EE/CA Reach.

The following assumptions were made in developing the conceptual design elements for riverbed restoration:

- The bed slope of each subreach will be the same grade after soil remediation activities are complete.

- Channel width of each subreach will remain the same. Assumed channel width equal to 50 to 60 ft (low-flow width).

- Overall habitat restoration objective is to maintain or enhance existing habitat conditions. Enhancement of habitat parameters includes: in-stream cover, substrate diversity, channel width and depth variability, and pool area.

Table L-5 provides the description and list of riverbed restoration techniques. In the table, subreaches are combined into two basic geomorphic classifications: relatively gentle bedslope (subreaches 3-8 to 3-10 and 4-4 to 4-6) and relatively steep bed slope (subreaches 4-1 to 4-3). Based on the existing substrate in these reaches and bed slope, these classifications also serve as general indicators of sediment transport. For the detailed restoration design, it may be appropriate to divide the subreach groupings into further classifications based on existing conditions (e.g., bank conditions, sinuosity, subdominant substrate, etc.). The lengths of straight channels and channel bends have been estimated from maps for this analysis. There is likely more bend length as map morphology has been simplified.

As a result of channel classification (based on slope, channel geometry, substrate), restoration objectives (i.e., longevity, protect soil), and civil infrastructure (e.g., roads, power lines, etc.), the following restoration techniques are applicable in the EE/CA Reach:

- Single-wing rock deflectors.

- Low-profile rock weirs (e.g., W-shaped).

- Boulder placement.

- Rock spurs.

- Limited application: double-wing rock deflector (where pool formation and channel narrowing is needed).

These design elements are described below:

Single-wing rock deflectors—Deflectors are placed along the riverbank. These structures need to be keyed into both bed and bank to prevent undermining and subsequent failure. To key the structure into the bed the channel will need to be excavated down to a relatively stable substrate surface (e.g., cobble, bedrock). If the streambed is predominantly sand and reaching a stable substrate is not practical, a filter layer or geotextile may be needed underneath the deflector.

These structures deflect flow downstream toward the opposite bank when they are angled upstream at 30 to 45 degrees. They can also be used in series, on opposite banks, to keep the flow in the center of the channel. Deflectors create fish hiding cover, dissipate stream energy, divert flows, protect streambanks, create small pools, and sort sediments. They are generally most effective when streamflows are greater than the 1- to 2-year flood.

Table L-5

Streambed Restoration: Existing Aquatic Habitat Conditions and Applicable In-Stream Restoration Structures*

Subreach	Average Bed Slope (%)	Predominant Substrate	Channel Length(ft)		Existing Habitat	Relative Potential To Enhance Aquatic Habitat				Subreach Aquatic Habitat Objectives	Applicable Restoration Structures
			Straight	Bend		In-stream cover	Substrate diversity	Channel width/depth variability	Pool area		
3-8 to 3-10 4-4 to 4-6	<0.1	Sand	3600	1600	99% riffle/run 1% pools (3 pools) Portions channelized Deposition zone Small, channel margin pools(L=50 ft) Uniform width/depth	low (moderate)	low	moderate (low)	low	(1) Maintain and increase number of small pools (2) Increase variability in channel width and depth (3) Increase in-stream cover/ roughness	Single wing deflectors alternating on opposite banks (L=5-20 ft) Rock spurs (L<5 ft)
4-1 to 4-3	0.2-0.5	Cobble	1800	400	85% riffle/run 15%pools (5 pools) Pool/riffle sequence Bedrock effects Transport zone Bigger pools (L=70 ft) Variable width/depth	high	moderate	moderate	high	(1) Maintain and increase number of bigger pools (2) Increase in-stream cover/ roughness (3) Increase diversity of substrate	Rock weirs (w-shaped) In-stream boulders Rock spurs (L<5 ft)

Notes: *Table is based on complete removal of contaminated soil - no sorptive cap is used.

Conversely, installing deflectors angled downstream and alternating the placement of deflectors on opposite banks can achieve some variability in channel width and depth at relatively low flows (i.e., < 1-year flood) and develop a thalweg. At low flows some channel meandering will develop and subsequently increase the diversity of habitat types. Small pools will develop on the downstream side of deflectors. Deflector height, length, angle, shape, and spacing need to be carefully designed as flows at higher stages can direct flow toward the riverbank and potentially cause erosion.

Deflectors are typically installed in straight reaches where channel width and depth variability, bank protection, and/or habitat structure are needed. Deflectors are easily constructed and their final design can be adjusted to satisfy a variety of objectives. Typically, deflector height needs to be at or below the low-flow level. The length of the deflector affects the downstream bed and bank scour potential. Length depends on channel width (typically 20 to 50% of width). The design spacing is a function of the width of the channel, length of deflector, streamflows, and the restoration objectives.

Low-profile rock weirs—These structures can create pools downstream, control stream grade, dissipate stream energy, sort sediments, and provide aquatic habitat. They generally span the channel width and are placed approximately one-third below bankfull height (at or below low-flow stage). W-shaped rock weirs are typically used on wide channels (>40 ft) and create a wide variety of depths and velocity ranges. Upstream pointing "V" shaped weirs may be used in narrow width locations and where reducing bank shear stress is needed as streamflows are focused into the center of the channel. Weirs are typically installed in straight portions of the channel where channels are relatively steep and substrate is coarse (e.g., subreach 4-1).

Spacing of weirs is primarily dependent on channel width, channel sinuosity, bed slope, and restoration objectives (e.g., increase size of pools). Typically pools are spaced 5 to 7 bankfull channel widths. For the EECA reach, this is about every 350 to 450 ft. Installation of weirs would only be applicable in subreaches (4-1 to 4-3) where there is a steeper bed slope. Currently there are five pools present in this area (L=70 ft, 15% pools). Maintaining this number or adding an additional pool could be a restoration objective for this area (20 to 25% pools may be possible).

Rock spurs (or barbs, rock jetties)—Rock spurs are typically angled upstream approximately 45 degrees, and are used primarily to protect streambanks from erosion. Rock spurs are short in length. Their length depends on channel width (approximately 5 to 10 ft in length for EE/CA reach), channel sinuosity, and restoration objectives. Spacing is generally two times their length and careful design is needed as rock spurs can cause bank erosion immediately downstream. Rock spurs are often used in series as each structure reduces the erosion potential from the spur placed immediately upstream. These structures can provide in-stream cover, dissipate stream energy, protect streambanks, and add some channel width and depth variability. They are generally installed on the outside portions of channel bends but can be applied in straight reaches as well.

Boulder placement—This type of restoration structure uses boulders that are placed in a cluster or alone in the river. Typical size for the boulders that could be used in the Housatonic River would range from 2 to 3 ft in diameter. Boulders create small scour areas downstream, provide cover for aquatic organisms, and dissipate stream energy by adding channel roughness. For stability and to be effective restoration components, the boulders need to be keyed into the bed or bank (approximately one-fourth to one-third its diameter).

Generally, boulder placement requires a relatively stable bed. Subreaches that are predominantly cobble in the EE/CA Reach, such as 4-1 and 4-2, would be applicable. A predominant sandbed, such as subreach 3-8, is not stable and boulder placement here would not be effective as erosion around the boulder would occur and eventually the boulder would get undermined and subsequently become buried.

The actual placement of the boulders will depend on the channel morphology (e.g., pool or riffle, bend or straight reach), types of other restoration structure used, and the specific subreach restoration objectives. Boulder placement is often used to enhance fish habitat both within pools and riffles, increase channel complexity (e.g., variability in flow patterns) and bed roughness, and protect streambanks.

The following additional considerations regarding this conceptual design are noted:

- Final riverbed restoration design will depend on the streambank stability structures used (types, locations, and length), adjustments due to model analyses (changes in sediment transport), and the post-soil remediation conditions of the river (e.g., slope and substrate). Since all these factors are interrelated, design development is expected to be an iterative process.

- Substrate may be needed in reaches 4-1 to 4-3 after soil remediation activities are completed.

As this design is conceptual in nature, the following items will need to be addressed in the preparation of a final riverbed restoration design:

- Further development of habitat restoration objectives is needed. The restoration objectives need to clearly define specific aquatic components (e.g., increase in pool area) that will be enhanced or restored so that restoration features (e.g., rock weirs) can be designed. Additionally, after the project has been completed these objectives can then be measured to evaluate the effectiveness of the restoration efforts.

- Some potential aquatic habitat objectives and associated measures: increase in-steam cover (area), substrate diversity (pebble counts), channel width and depth variability (channel geometry, standard deviation of width and depth), and/or pool area (area, longitudinal profile).

- More research is needed to determine spacing between single-wing deflectors: literature search, field investigation (spacing of existing bank features), and consultation.

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